

15TH EDITION

Guyton and Hall Textbook of Medical Physiology

John E. Hall, PhD

Arthur C. Guyton Professor and Chair
Department of Physiology and Biophysics
Director, Mississippi Center for Obesity Research
University of Mississippi Medical Center
Jackson, Mississippi

Michael E. Hall, MD, MS

Chair and Professor
Department of Medicine, Division of
Cardiovascular Diseases
Department of Physiology and Biophysics
Patrick H. Lehan Chair of Cardiovascular Diseases
Director of Clinical and Population Studies,
Mississippi Center for Clinical and
Translational Research
University of Mississippi Medical Center
Jackson, Mississippi



Contents

UNIT I

Introduction to Physiology: The Cell and General Physiology

CHAPTER 1

Functional Organization of the Human Body and Control of the “Internal Environment”	3
Cells Are the Living Units of the Body	3
Extracellular Fluid—The “Internal Environment”	3
Homeostasis—Maintenance of a Stable Internal Environment	4
Control Systems of the Body	7
Physiological Variability	10
Sex Differences in Physiology and Pathophysiology	10
Summary—Automaticity of the Body	11

CHAPTER 2

The Cell and Its Functions	13
Organization of the Cell	13
Cell Structure	14
Functional Systems of the Cell	21
Locomotion of Cells	26

CHAPTER 3

Genetic Control of Protein Synthesis, Cell Function, and Cell Reproduction	31
Cell Nucleus Genes Control Protein Synthesis	31
Transcription—Transfer of Cell Nucleus DNA Code to Cytoplasm RNA Code	33
Translation—Formation of Proteins on the Ribosomes	37
Protein Enzymes Control Synthesis of Other Substances in the Cell	38
Regulation of Gene Function and Biochemical Activity in Cells	39
The DNA—Genetic System Controls Cell Reproduction	41
Cell Differentiation	45
Apoptosis—Programmed Cell Death	46
Cancer	46

UNIT II

Membrane Physiology, Nerve, and Muscle

CHAPTER 4

Transport of Substances Through Cell Membranes	51
The Cell Membrane Is a Lipid Bilayer With Cell Membrane Transport Proteins	51
Diffusion	52
Active Transport of Substances Through Membranes	58

CHAPTER 5

Membrane Potentials and Action Potentials	63
Basic Physics of Membrane Potentials	63
Resting Membrane Potential of Neurons	65
Neuron Action Potential	67
Propagation of the Action Potential	71
Importance of Energy Metabolism for Reestablishing Sodium and Potassium Ionic Gradients After Action Potentials Are Completed	72
Plateau in Some Action Potentials	72
Rhythmicity of Some Excitable Tissues—Repetitive Discharge	73
Special Characteristics of Signal Transmission in Nerve Trunks	74
Excitation—The Process of Eliciting the Action Potential	75

CHAPTER 6

Contraction of Skeletal Muscle	79
Physiological Anatomy of Skeletal Muscle	79
General Mechanism of Muscle Contraction	81
Molecular Mechanisms of Muscle Contraction	82
Energetics of Muscle Contraction	86
Characteristics of Whole Muscle Contraction	87

CHAPTER 7

Excitation of Skeletal Muscle: Neuromuscular Transmission and Excitation-Contraction Coupling 93

Neuromuscular Junction and Transmission of Impulses From Nerve Endings to Skeletal Muscle Fibers 93

Muscle Action Potential 97

Excitation-Contraction Coupling 97

CHAPTER 8

Excitation and Contraction of Smooth Muscle 101

Contraction of Smooth Muscle 101

Regulation of Contraction By Calcium Ions 103

Nervous and Hormonal Control of Smooth Muscle Contraction 105

UNIT III

The Heart

CHAPTER 9

Cardiac Muscle; The Heart as a Pump and Function of the Heart Valves 113

Cardiac Muscle Physiology 113

The Cardiac Cycle 118

Regulation of Heart Pumping 123

CHAPTER 10

Rhythmical Excitation of the Heart 127

Specialized Excitatory and Conductive System of the Heart 127

Control of Excitation and Conduction in the Heart 131

CHAPTER 11

Fundamentals of Electrocardiography 135

Waveforms of the Normal Electrocardiogram 135

Flow of Current Around the Heart During the Cardiac Cycle 137

Electrocardiographic Leads 138

CHAPTER 12

Electrocardiographic Interpretation of Cardiac Muscle and Coronary Blood Flow Abnormalities: Vectorial Analysis 143

Vectorial Analysis of Electrocardiograms 143

Vectorial Analysis of the Normal Electrocardiogram 145

Mean Electrical Axis of the Ventricular QRS and Its Significance 148

Conditions That Cause Abnormal Voltages of the QRS Complex 150

Prolonged and Bizarre Patterns of the QRS Complex 151

Current of Injury on the Electrocardiogram 152

Abnormalities in the T Wave 155

CHAPTER 13

Cardiac Arrhythmias and Their Electrocardiographic Interpretation 159

Abnormal Sinus Rhythms 159

Heart Block Within the Intracardiac Conduction Pathways 160

Premature Contractions 162

Paroxysmal Tachycardia 164

Ventricular Fibrillation 165

Atrial Fibrillation 168

Atrial Flutter 169

Cardiac Arrest 170

UNIT IV

The Circulation

CHAPTER 14

Overview of the Circulation: Pressure, Flow, and Resistance 173

Physical Characteristics of the Circulation 173

Basic Principles of Circulatory Function 175

Interrelationships of Pressure, Flow, and Resistance 175

CHAPTER 15

Vascular Distensibility and Functions of the Arterial and Venous Systems 183

Vascular Distensibility 183

Arterial Pressure Pulsations 184

Veins and Their Functions 188

CHAPTER 16

The Microcirculation and Lymphatic System: Capillary Fluid Exchange, Interstitial Fluid, and Lymph Flow 193

Structure of the Microcirculation and Capillary System 193

Vasomotion Causes Intermittent Capillary Blood Flow 194

Exchange of Substances Between the Blood and Interstitial Fluid 195

Interstitial and Interstitial Fluid 196

Fluid Filtration Across Capillaries 197

Lymphatic System 201

CHAPTER 17		
Local and Humoral Control of Tissue Blood Flow	207	
Local Blood Flow Is Controlled in Response to Tissue Needs	207	
Mechanisms of Local Blood Flow Control	207	
Humoral Control of the Circulation	216	
CHAPTER 18		
Nervous Regulation of the Circulation and Rapid Control of Arterial Pressure	219	
Nervous Regulation of the Circulation	219	
Special Features of Nervous Control of Arterial Pressure	228	
CHAPTER 19		
Role of the Kidneys in Long-Term Control of Arterial Pressure and in Hypertension: The Integrated System for Arterial Pressure Regulation	231	
Renal–Body Fluid System for Arterial Pressure Control	231	
Role of the Renin-Angiotensin System in Arterial Pressure Control	238	
Summary of Integrated Multifaceted Systems for Arterial Pressure Regulation	245	
CHAPTER 20		
Cardiac Output, Venous Return, and Their Regulation	249	
Normal Values for Cardiac Output at Rest and During Activity	249	
Control of Cardiac Output By Venous Return—Frank-Starling Mechanism of the Heart	249	
Methods for Measuring Cardiac Output	260	
CHAPTER 21		
Muscle Blood Flow and Cardiac Output During Exercise; The Coronary Circulation and Ischemic Heart Disease	263	
Blood Flow Regulation in Skeletal Muscle at Rest and During Exercise	263	
Coronary Circulation	266	
CHAPTER 22		
Heart Failure	275	
Circulatory Dynamics in Heart Failure	275	
Unilateral Left Heart Failure	279	
Low-Output Cardiac Failure—Cardiogenic Shock	279	
Edema in Patients With Heart Failure	280	
Cardiac Reserve	282	
Quantitative Graphic Analysis of Cardiac Failure	282	
Heart Failure With Preserved Ejection Fraction	284	
High-Output Heart Failure	285	
CHAPTER 23		
Heart Valves and Heart Sounds; Valvular and Congenital Heart Defects	287	
Heart Sounds	287	
Abnormal Circulatory Dynamics in Valvular Heart Disease	291	
Abnormal Circulatory Dynamics in Congenital Heart Defects	293	
Use of Extracorporeal Circulation During Cardiac Surgery	295	
Hypertrophy of the Heart in Valvular and Congenital Heart Disease	295	
CHAPTER 24		
Circulatory Shock and Its Treatment	297	
Physiological Causes of Shock	297	
Hypovolemic Shock Due to Hemorrhage	298	
Distributive Shock Is Characterized By Severe Peripheral Vasodilation	303	
Obstructive Shock Is Usually Due to Noncardiac Causes of Reduced Cardiac Output	305	
Physiology of Treatment in Shock	305	
Circulatory Arrest	306	
UNIT V		
The Body Fluids and Kidneys		
CHAPTER 25		
Regulation of Body Fluid Compartments: Extracellular and Intracellular Fluids; Edema	309	
Intake and Output of Fluids and Solutes Are Balanced During Long-Term Steady-State Conditions	309	
Body Fluid Compartments	310	
Constituents of Extracellular and Intracellular Fluids	311	
Measurement of Body Fluid Compartment Volumes—Indicator-Dilution Principle	312	
Fluid Exchange and Osmotic Equilibrium Between Intracellular and Extracellular Fluid	314	
Volume and Osmolality of Extracellular and Intracellular Fluids in Abnormal States	316	
Glucose and Other Solutions Administered for Nutritive Purposes	317	
Clinical Abnormalities of Fluid Volume Regulation: Hyponatremia and Hypernatremia	318	
Edema: Excess Fluid in the Tissues	320	
Fluids in Potential Spaces of the Body	324	

CHAPTER 26		<i>Regulation of Renal Phosphate Excretion</i>	400
The Urinary System: Functional Anatomy and Urine Formation By the Kidneys		<i>Regulation of Renal Magnesium Excretion and Extracellular Magnesium Ion Concentration</i>	401
Multiple Functions of the Kidneys	325	<i>Integration of Renal Mechanisms for Control of Extracellular Fluid</i>	401
Physiological Anatomy of the Kidneys	326	<i>Distribution of Extracellular Fluid Between Interstitial Spaces and Vascular System</i>	404
Urine Formation Results From Glomerular Filtration, Tubular Reabsorption, and Tubular Secretion	328	<i>Nervous and Hormonal Factors Increase Effectiveness of Renal–Body Fluid Feedback Control</i>	405
Micturition	331	<i>Integrated Responses to Changes in Sodium Intake</i>	407
CHAPTER 27		<i>Conditions That Cause Large Increases in Blood Volume and Extracellular Fluid Volume</i>	408
Glomerular Filtration, Renal Blood Flow, and Their Control		<i>Conditions That Cause Large Increases in Extracellular Fluid Volume With Normal or Reduced Blood Volume</i>	409
Glomerular Filtration—The First Step in Urine Formation	335	CHAPTER 31	
Determinants of GFR	337	Acid–Base Regulation	
Renal Blood Flow	340	<i>Hydrogen Ion Concentration Is Precisely Regulated</i>	
<i>Physiological Control of GFR and Renal Blood Flow</i>	341	411	
Autoregulation of GFR and Renal Blood Flow	343	<i>Acids and Bases—Definitions and Meanings</i>	
CHAPTER 28		411	
Renal Tubular Reabsorption and Secretion		411	
Tubular Reabsorption Is Quantitatively Large and Highly Selective	349	<i>Defending Against Changes in H⁺ Concentration: Buffers, Lungs, and Kidneys</i>	
Tubular Reabsorption Includes Passive and Active Mechanisms	349	412	
Reabsorption and Secretion Along Different Parts of the Nephron	355	<i>Buffering of H⁺ in the Body Fluids</i>	
Regulation of Tubular Reabsorption	361	412	
Use of Clearance Methods to Quantify Kidney Function	367	<i>Bicarbonate Buffer System</i>	
CHAPTER 29		413	
Urine Concentration and Dilution; Regulation of Extracellular Fluid Osmolarity and Sodium Concentration		415	
Kidneys Excrete Excess Water By Forming Dilute Urine	373	415	
Kidneys Conserve Water By Excreting Concentrated Urine	374	<i>Proteins Are Important Intracellular Buffers</i>	
Countercurrent Multiplier Mechanism	376	415	
Control of Extracellular Fluid Osmolarity and Sodium Concentration	383	<i>Respiratory Regulation of Acid–Base Balance</i>	
CHAPTER 30		416	
Renal Regulation of Potassium, Calcium, Phosphate, and Magnesium; Integration of Renal Mechanisms for Control of Blood Volume and Extracellular Fluid Volume		417	
Regulation of Internal Potassium Distribution	391	<i>Renal Control of Acid–Base Balance</i>	
Regulation of Renal Potassium Excretion	392	417	
Regulation of Renal Calcium Excretion and Extracellular Calcium Ion Concentration	397	<i>Secretion of H⁺ and Reabsorption of HCO₃⁻ By the Renal Tubules</i>	
		418	
		<i>Combination of Excess H⁺ With Phosphate and Ammonia Buffers in the Tubule Generates “New” HCO₃⁻</i>	
		420	
		<i>Quantifying Renal Acid–Base Excretion</i>	
		422	
		<i>Regulation of Renal Tubular H⁺ Secretion</i>	
		422	
		<i>Renal Correction of Acidosis—Increased Excretion of H⁺ and Addition of HCO₃⁻ to the Extracellular Fluid</i>	
		423	
		<i>Renal Correction of Alkalosis—Decreased Tubular Secretion of H⁺ and Increased Excretion of HCO₃⁻</i>	
		424	
		CHAPTER 32	
		Diuretics and Kidney Diseases	
		429	
		<i>Diuretics and Their Mechanisms of Action</i>	
		429	
		<i>Kidney Diseases</i>	
		431	
		<i>Acute Kidney Injury</i>	
		432	
		<i>CKD Is Often Associated With Irreversible Loss of Functional Nephrons</i>	
		434	

UNIT VI

Blood Cells, Immunity, and Blood Coagulation

CHAPTER 33
Red Blood Cells, Anemia, and Polycythemia 447
 Red Blood Cells (Erythrocytes) 447
 Iron Metabolism 452
 Anemias 454
 Polycythemia 455

CHAPTER 34
Resistance of the Body to Infection: I. Leukocytes, Granulocytes, the Monocyte-Macrophage System, and Inflammation 457
 Leukocytes (White Blood Cells) 457
 Neutrophils and Macrophages Defend Against Infections 459
 Monocyte-Macrophage Cell System (Reticuloendothelial System) 460
 Inflammation: Role of Neutrophils and Macrophages 462
 Eosinophils 464
 Basophils 465
 Leukopenia 465
 Leukemias 465

CHAPTER 35
Resistance of the Body to Infection: II. Immunity and Allergy 467
 Acquired (Adaptive) Immunity 467
 Allergy and Hypersensitivity 477
 Sex Differences in Innate and Adaptive Immunity 479

CHAPTER 36
Blood Types, Transfusion, and Tissue and Organ Transplantation 481
 Antigenicity Causes Immune Reactions of Blood 481
 O-A-B Blood Types 481
 Rh Blood Types 483
 Transfusion Reactions Resulting From Mismatched Blood Types 484
 Transplantation of Tissues and Organs 485

CHAPTER 37
Hemostasis and Blood Coagulation 487
 Hemostasis Events 487
 Mechanism of Blood Coagulation 489
 Conditions That Cause Excessive Bleeding in Humans 494
 Thromboembolic Conditions 496
 Anticoagulants for Clinical Use 497
 Blood Coagulation Tests 497

UNIT VII

Respiration

CHAPTER 38
Pulmonary Ventilation 501
 Mechanics of Pulmonary Ventilation 501
 Pulmonary Volumes and Capacities 504
 Alveolar Ventilation 507

CHAPTER 39
Pulmonary Circulation, Pulmonary Edema, and Pleural Fluid 513
 Physiological Anatomy of the Pulmonary Circulatory System 513
 Pressures in the Pulmonary Circulatory System 513
 Blood Volume of the Lungs 514
 Blood Flow Through the Lungs and Its Distribution 514
 Effect of Hydrostatic Pressure Gradients in the Lungs on Regional Pulmonary Blood Flow 515
 Pulmonary Capillary Dynamics 517
 Fluid in the Pleural Cavity 519

CHAPTER 40
Principles of Gas Exchange; Diffusion of Oxygen and Carbon Dioxide Through Respiratory Membranes 521
 Compositions of Alveolar Air and Atmospheric Air Are Different 523
 Diffusion of Gases Through the Respiratory Membrane 525

CHAPTER 41
Transport of Oxygen and Carbon Dioxide in Blood and Tissue Fluids 531
 Transport of Oxygen From the Lungs to the Body Tissues 531
 Transport of CO₂ in Blood 538
 Respiratory Exchange Ratio 540

CHAPTER 42
Regulation of Respiration 541
 Respiratory Center 541
 Chemical Control of Respiration 543
 Peripheral Chemoreceptor System—Role of Oxygen in Respiratory Control 544
 Regulation of Respiration During Exercise 547

CHAPTER 43
Respiratory Insufficiency—Pathophysiology, Diagnosis, Oxygen Therapy 551
 Methods for Studying Respiratory Abnormalities 551

Pathophysiology of Specific Pulmonary Abnormalities	553
Hypoxia and Oxygen Therapy	556
Hypercapnia—Excess Carbon Dioxide in the Body Fluids	558
Respiratory Resuscitation and Mechanical Ventilators	558

UNIT VIII

Aviation, Space, and Deep-Sea Diving Physiology

CHAPTER 44	
Aviation, High Altitude, and Space Physiology	563
Effects of Low Oxygen Pressure on the Body	563
CHAPTER 45	
Physiology of Deep-Sea Diving and Other Hyperbaric Conditions	571
Effect of High Partial Pressures of Individual Gases on the Body	571
Self-Contained Underwater Breathing Apparatus (SCUBA) Diving	575

UNIT IX

The Nervous System: A. General Principles and Sensory Physiology

CHAPTER 46	
Organization of the Nervous System, Basic Functions of Synapses and Neurotransmitters	579
General Design of the Nervous System	579
Major Levels of Central Nervous System Function	581
Comparison of the Nervous System to a Computer	582
Central Nervous System Synapses	582
Special Characteristics of Synaptic Transmission	595
CHAPTER 47	
Sensory Receptors and Neuronal Circuits for Processing Information	597
Types of Sensory Receptors and the Stimuli They Detect	597
Transduction of Sensory Stimuli Into Nerve Impulses	598
Signal Intensity Transmission in Nerve Tracts—Spatial and Temporal Summation	602
Transmission and Processing of Signals in Neuronal Pools	603
Instability and Stability of Neuronal Circuits	607

CHAPTER 48	
Somatic Sensations: I. General Organization, Tactile and Position Senses	609
Classification of Somatic Senses	609
Detection and Transmission of Tactile Sensations	609
Sensory Pathways for Transmitting Somatic Signals Into the Central Nervous System	611
Transmission in the Dorsal Column—Medial Lemniscal System	611
Transmission of Sensory Signals in the Anterolateral Pathway	619

CHAPTER 49	
Somatic Sensations: II. Pain, Headache, and Thermal Sensations	623
Fast Pain and Slow Pain and Their Qualities	623
Pain Receptors (Nociceptors) and Their Stimulation	623
Dual Pathways for Transmission of Pain Signals Into the Central Nervous System	624
Pain Suppression (Analgesia) System in the Brain and Spinal Cord	626
Referred Pain	628
Visceral Pain	628
Thermal Sensations	632

UNIT X

The Nervous System: B. The Special Senses

CHAPTER 50	
The Eye: I. Optics of Vision	637
Physical Principles of Optics	637
Optics of the Eye	640
Fluid System of the Eye—Intraocular Fluid	646
CHAPTER 51	
The Eye: II. Receptor and Neural Function of the Retina	649
Anatomy and Function of Structural Elements of the Retina	649
Photochemistry of Vision	651
Color Vision	655
Neural Function of the Retina	656
CHAPTER 52	
The Eye: III. Central Neurophysiology of Vision	663
Visual Pathways	663
Organization and Function of the Visual Cortex	664
Neuronal Patterns of Stimulation During Analysis of Visual Images	666

Eye Movements and Their Control	667	Functions of Specific Cortical Areas	740
Autonomic Control of Accommodation and Pupillary Aperture	671	The Corpus Callosum and Anterior Commissure Transfer Thoughts, Memories, Training, and Other Information Between the Two Cerebral Hemispheres	746
CHAPTER 53		Thoughts, Consciousness, and Memory	747
The Sense of Hearing	675	CHAPTER 59	
Tympanic Membrane and the Ossicular System	675	The Limbic System and the Hypothalamus— Behavioral and Motivational Mechanisms of the Brain	753
Cochlea	676	Activating—Driving Systems of the Brain	753
Central Auditory Mechanisms	681	Limbic System	756
CHAPTER 54		The Hypothalamus, a Major Control Headquarters for the Limbic System	757
The Chemical Senses—Taste and Smell	687	Specific Functions of Other Parts of the Limbic System	761
Sense of Taste	687	CHAPTER 60	
Sense of Smell	691	States of Brain Activity—Sleep, Brain Waves, Epilepsy, Psychoses, and Dementia	765
		Sleep	765
UNIT XI		CHAPTER 61	
The Nervous System: C. Motor and Integrative Neurophysiology		The Autonomic Nervous System and the Adrenal Medulla	777
CHAPTER 55		General Organization of the Autonomic Nervous System	777
Spinal Cord Motor Functions; The Cord Reflexes	697	Basic Characteristics of Sympathetic and Parasympathetic Function	779
Organization of the Spinal Cord for Motor Functions	697	Selective Stimulation of Target Organs By Sympathetic and Parasympathetic Systems or “Mass Discharge”	787
Muscle Sensory Receptors—Muscle Spindles and Golgi Tendon Organs—and Their Roles in Muscle Control	699	CHAPTER 62	
Flexor Reflex and the Withdrawal Reflexes	703	Cerebral Blood Flow, Cerebrospinal Fluid, and Brain Metabolism	791
Crossed Extensor Reflex	705	Cerebral Blood Flow	791
Reciprocal Inhibition and Reciprocal Innervation	705	Cerebral Microcirculation	794
Reflexes of Posture and Locomotion	705	Cerebrospinal Fluid System	794
		Brain Metabolism	798
CHAPTER 56		UNIT XII	
Cortical and Brain Stem Control of Motor Function	709	Gastrointestinal Physiology	
Motor Cortex and Corticospinal Tract	709	CHAPTER 63	
Control of Motor Functions By the Brain Stem	715	General Principles of Gastrointestinal Function—Motility, Nervous and Hormonal Control, Blood Circulation, and Microbiota	803
Vestibular Sensations and Maintenance of Equilibrium	716	General Principles of Gastrointestinal Motility	803
CHAPTER 57		Neural Control of Gastrointestinal Function—Enteric Nervous System	805
Cerebellum and Basal Ganglia Contributions to Overall Motor Control	723	Hormonal Control of Gastrointestinal Motility	807
The Cerebellum and Its Motor Functions	723		
The Basal Ganglia and Their Motor Functions	732		
Integration of the Many Parts of the Entire Motor Control System	736		
CHAPTER 58			
Cerebral Cortex, Intellectual Functions of the Brain, Learning, and Memory	739		
Physiological Anatomy of the Cerebral Cortex	739		

Functional Movements in the Gastrointestinal Tract	809
Gastrointestinal Blood Flow—Splanchnic Circulation	810
Gastrointestinal Microbiota	812

CHAPTER 64

Propulsion and Mixing of Food in the Alimentary Tract	815
Ingestion of Food	815
Motor Functions of the Stomach	817
Movements of the Small Intestine	820
Movements of the Colon	822
Other Autonomic Reflexes That Affect Bowel Activity	824

CHAPTER 65

Secretory Functions of the Alimentary Tract	825
General Principles of Alimentary Tract Secretion	825
Secretion of Saliva	827
Gastric Secretion	829
Pancreatic Secretion	832
Bile Secretion By the Liver	835
Secretions of the Small Intestine	838
Secretion of Mucus By the Large Intestine	839

CHAPTER 66

Digestion and Absorption in the Gastrointestinal Tract	841
Digestion of Various Foods By Hydrolysis	841
Basic Principles of Gastrointestinal Absorption	845
Absorption in the Small Intestine	846
Absorption in the Large Intestine and Formation of Feces	850

CHAPTER 67

Physiology of Gastrointestinal Disorders	851
---	------------

UNIT XIII

Metabolism and Temperature Regulation

CHAPTER 68

Metabolism of Carbohydrates and Formation of Adenosine Triphosphate	861
--	------------

CHAPTER 69

Lipid Metabolism	871
Basic Chemical Structure of Triglycerides (Neutral Fat)	871
Transport of Lipids in the Body Fluids	871

CHAPTER 70

Protein Metabolism	883
---------------------------	------------

CHAPTER 71

The Liver	889
Physiological Anatomy of the Liver	889
Hepatic Vascular and Lymph Systems	889
Metabolic Functions of the Liver	891

CHAPTER 72

Dietary Balances; Regulation of Feeding; Obesity and Starvation; Vitamins and Minerals	897
Energy Intake and Output Are Balanced Under Steady-State Conditions	897
Regulation of Food Intake and Energy Storage	899

CHAPTER 73

Energetics and Metabolic Rate	915
--------------------------------------	------------

CHAPTER 74

Body Temperature Regulation and Fever	923
Normal Body Temperatures	923
Body Temperature Is Controlled By Balancing Heat Production and Heat Loss	923
Regulation of Body Temperature—Role of the Hypothalamus	927
Abnormalities of Body Temperature Regulation	931

UNIT XIV

Endocrinology and Reproduction

CHAPTER 75

Introduction to Endocrinology	937
Coordination of Body Functions By Chemical Messengers	937
Chemical Structure and Synthesis of Hormones	937
Hormone Secretion, Transport, and Clearance From the Blood	941
Mechanisms of Action of Hormones	942

CHAPTER 76

Pituitary Hormones and Their Control By the Hypothalamus	951
Pituitary Gland and Its Relation to the Hypothalamus	951
The Hypothalamus Controls Pituitary Secretion	952
Physiological Functions of Growth Hormone	954
Posterior Pituitary Gland and Its Relation to the Hypothalamus	961

CHAPTER 77

Thyroid Metabolic Hormones	965
Synthesis and Secretion of Thyroid Metabolic Hormones	965

Physiological Functions of the Thyroid Hormones	968	Male Sexual Act	1042
Regulation of Thyroid Hormone Secretion	972	Testosterone and Other Male Sex Hormones	1043
CHAPTER 78		CHAPTER 82	
Adrenocortical Hormones	979	Female Physiology Before Pregnancy and Female Hormones	1053
Corticosteroids: Mineralocorticoids, Glucocorticoids, and Androgens	979	Physiological Anatomy of the Female Sexual Organs	1053
Synthesis and Secretion of Adrenocortical Hormones	979	Female Hormonal System	1053
Functions of Mineralocorticoids—Aldosterone	982	Monthly Ovarian Cycle and Function of Gonadotropic Hormones	1054
Functions of Glucocorticoids	986	Functions of Ovarian Hormones—Estradiol and Progesterone	1058
CHAPTER 79		Regulation of Female Monthly Rhythm—Interplay Between Ovarian and Hypothalamic-Pituitary Hormones	1063
Insulin, Glucagon, and Diabetes Mellitus	999	Female Sexual Act	1068
Insulin and Its Metabolic Effects	999	CHAPTER 83	
Glucagon and Its Functions	1008	Pregnancy and Lactation	1073
Summary of Blood Glucose Regulation	1010	Maturation and Fertilization of the Ovum	1073
CHAPTER 80		Early Nutrition of the Embryo	1075
Parathyroid Hormone, Calcitonin, Calcium and Phosphate Metabolism, Vitamin D, Bone, and Teeth	1017	Anatomy and Function of the Placenta	1075
Overview of Calcium and Phosphate Regulation in Extracellular Fluid and Plasma	1017	Hormonal Factors in Pregnancy	1077
Bone and Its Relationship to Extracellular Calcium and Phosphate	1019	Parturition—Birth of the Baby	1082
Vitamin D	1023	Lactation	1085
Parathyroid Hormone	1025	CHAPTER 84	
Calcitonin	1028	Fetal and Neonatal Physiology	1089
Summary of Control of Calcium Ion Concentration	1029	UNIT XV	
Physiology of the Teeth	1032	Sports Physiology	
CHAPTER 81		CHAPTER 85	
Reproductive and Hormonal Functions of the Male (and Function of the Pineal Gland)	1037	Sports Physiology	1101
Spermatogenesis	1037		